

TRACE FOSSILS FROM A SUBMARINE FAN-SLOPE APRON COMPLEX IN THE CRETACEOUS OF JAMES ROSS ISLAND, ANTARCTICA

J. R. INESON

*British Antarctic Survey, Natural Environment Research Council, High Cross,
Madingley Road, Cambridge CB3 0ET, UK*

ABSTRACT. The Kotick Point and Whisky Bay Formations (Aptian–Coniacian) of NW James Ross Island represent slope apron and proximal submarine fan deposits of a marine back-arc basin. Although classical deep-water trace fossils are represented, the ichnofauna includes several forms typically assigned to shallow-water environments and trace fossil assemblages are closely tied to sedimentary facies. Mud-rich, slope apron deposits are characterized by the assemblage *Chondrites–Zoophycos–Planolites–Teichichnus* whereas coarse, sandy fan sequences typically contain the assemblage *Thalassinoides–Ophiomorpha–Palaeophycus*. Clearly, in such a proximal marine setting, substrate and local energy levels are more influential than absolute bathymetry.

INTRODUCTION

Since the work of Seilacher (1976), the study of trace fossils has contributed greatly to palaeoenvironmental interpretation of marine sedimentary rocks. Recent work on both modern and ancient deposits, however, has demonstrated that many ichnogenera which were previously thought to be restricted to specific bathymetric zones, occur through a range of depositional environments (e.g. Kern and Warne, 1974; Crimes, 1977; Buck and Bottjer, 1985). In particular, study of ancient and modern deep-sea sediments has revealed forms such as *Skolithos*, *Ophiomorpha* and *Thalassinoides*, which are often considered to be typical of the shallow marine shelf (e.g. Curran, 1985). The aim of this paper is to describe the ichnofauna of the Kotick Point and Whisky Bay Formations (Aptian–Coniacian) of the Gustav Group of James Ross Island, Antarctica and, in particular, to emphasise the presence of supposed 'shallow-water' trace fossils within this succession of slope apron and submarine fan siliciclastics.

STRATIGRAPHY AND DEPOSITIONAL SETTING

The Gustav Group is part of a thick, mainly undeformed succession of marine clastic rocks of Cretaceous–early Tertiary age, cropping out on the east side of the Antarctic Peninsula (Fig. 1). These rocks are the fill of a back-arc basin that lay to the east of an active, emergent volcanic arc, now represented by the spine of the Antarctic Peninsula (Fig. 1). The most extensive exposure of this basin fill is on James Ross Island and surrounding islands, where the succession has a thickness of at least 5 km. The Gustav Group is the basal stratigraphic unit of this succession; it has an age range of approximately Barremian–Santonian and a total thickness of about 2300 m. It comprises an alternation of coarse-grained and fine-grained units which have been grouped into four formations (Fig. 2; Ineson and others, 1986). The basal formation is recognized only in isolated outcrops at Lagrelius Point (Figs. 1, 2); the trace fossils described here occur within the overlying Kotick Point and Whisky Bay Formations, which crop out along the length of the north-west coast of James Ross Island (Fig. 1).

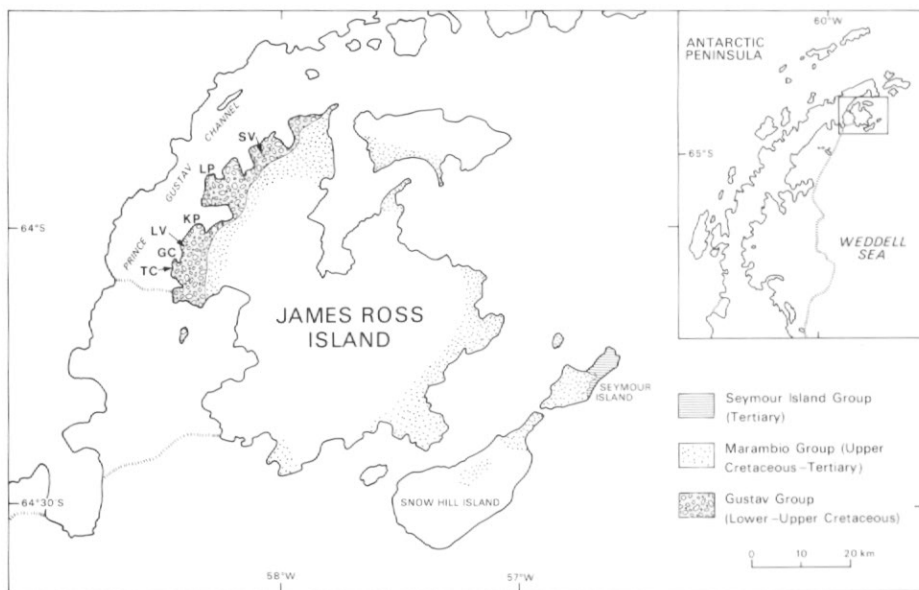


Fig. 1. Sketch geological map of the northern Antarctic Peninsula showing the distribution of Cretaceous-Tertiary sedimentary rocks in the James Ross Island region. SV, Sharp Valley; LP, Lagrelius Point; KP, Kotick Point; LV, Lost Valley; GC, Gin Cove; TC, Tumbledown Cliffs.

The rocks of the Lagrelius Point, Kotick Point and Whisky Bay Formations (Fig. 2) can be broadly subdivided into fine-grained, mud-dominated units and coarse-grained, conglomerate- and sandstone-dominated units. These represent deposition in slope apron and submarine fan environments respectively, proximal to a tectonically controlled basin margin (Farquharson and others, 1984; Ineson, 1985*a, b*). Slope apron sequences comprise bioturbated silty, sandy mudstones interbedded with thin-bedded, fine-grained sandstone turbidites. Slump folds, stacked intraformational slump sheets, exotic slide blocks and chaotic mass-flow deposits testify to a lower slope or base-of-slope setting. Submarine fan deposits include channelled coarse-grained conglomerates and pebbly sandstones representing the proximal channelled zone of coarse-grained fan systems.

The overlying Hidden Lake Formation, however, was deposited under more varied palaeoenvironmental conditions. A localized unconformity at the base of the formation (Fig. 2) records a phase of basin uplift and preliminary study of the sedimentology and ichnology of the Hidden Lake Formation suggests a shallow-marine environment. This paper is concerned only with the trace-fossil record from the deeper-water Kotick Point and Whisky Bay Formations.

SYSTEMATIC DESCRIPTIONS

Mudstones and sandstones of the Kotick Point and Whisky Bay Formations are typically moderately to intensely bioturbated, often to the point of complete destruction of bedding and primary sedimentary structures. Intensive bioturbation commonly results in a mottled, homogenized fabric without recognizable form, particularly in sand-dominated intervals. Ten distinct traces were recognized, however, and eight of these are assigned to ichnogenera.

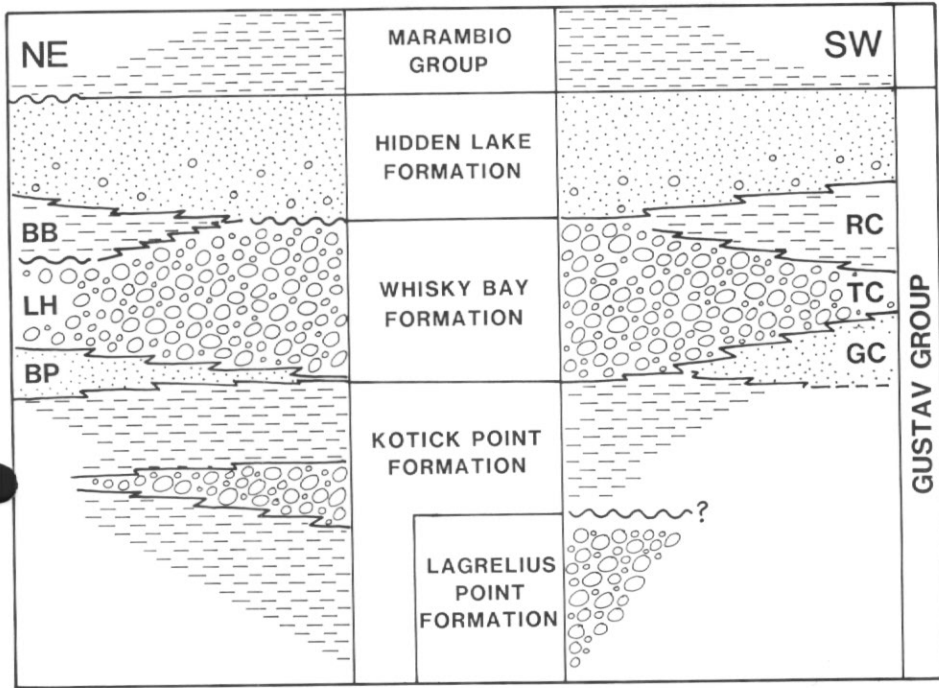


Fig. 2. Lithostratigraphy of the Cretaceous sedimentary strata on the west coast of James Ross Island (after Ineson and others, 1986). Circled ornament = conglomerate-dominated; stippled = sandstone-dominated; dashed = mudstone-dominated. Whisky Bay Formation members: BP, Bibby Point Member; LH, Lewis Hill Member; BB, Brandy Bay Member; GC, Gin Cove Member; TC, Tumbledown Cliffs Member; RC, Rum Cove Member.

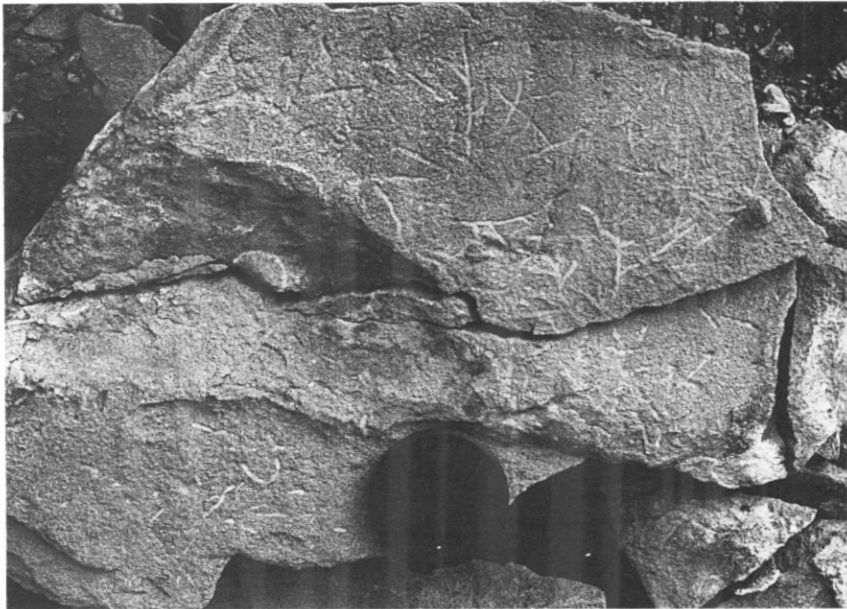


Fig. 3. Bedding plane view of *Chondrites*. Diameter of lens cap is 5 cm (also in Figs. 5, 6 and 9). Tumbledown Cliffs Member, Whisky Bay Formation; south Tumbledown Cliffs.

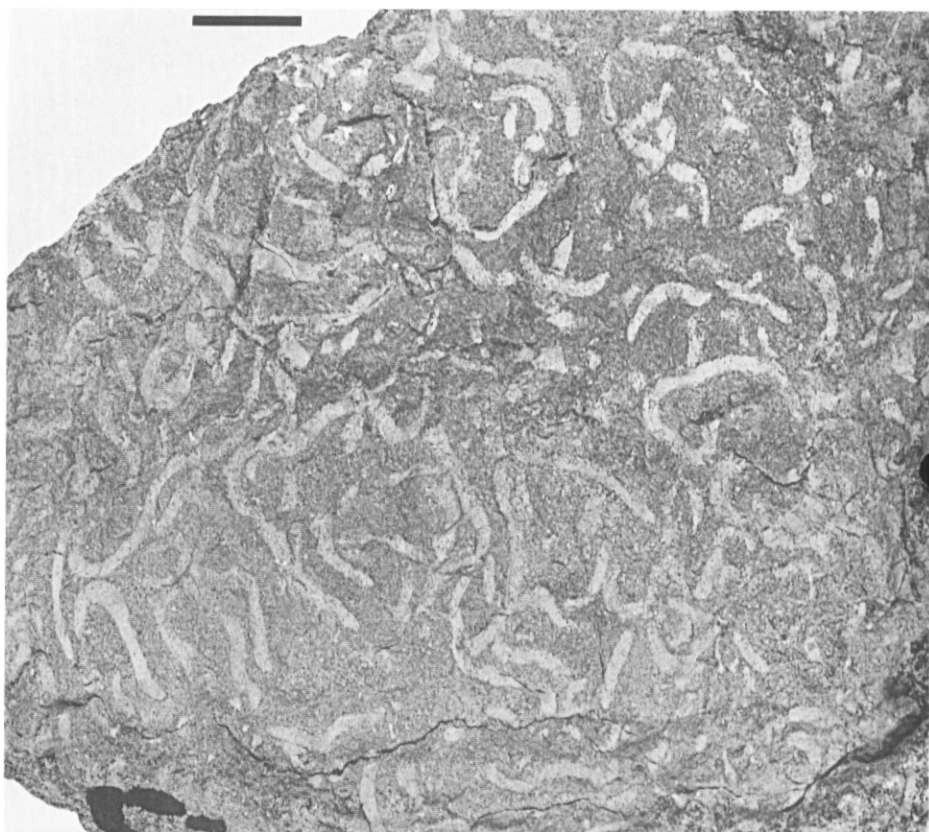


Fig. 4. *Phycosiphon* on sandy siltstone bedding plane. D8508.5, scale bar = 1 cm. Kotick Point Formation; Kotick Point.

Ichnogenus CHONDRITES von Sternberg, 1833

Chondrites ichnosp.

Figs. 3, 7, 10

Description. Regular dendritic branching pattern of small sediment-filled endichnia burrows. Circular to oval in cross-section where uncompacted. Diameter 0.2–2 mm; diameter uniform within individual burrow systems but narrow (0.2–0.5 mm diameter) and wide (1–2 mm diameter) systems often occur together. Branching angles variable; offshoots often begin at 20–30° to parent tunnel and curve gently outwards (cf. *C. recurvus*). Branches of same system rarely cross or intersect one another. Burrows generally parallel to bedding; oblique upward and downward offshoots present locally. Unlined tunnels, structureless mud fill.

Occurrence. Common throughout succession (Fig. 13); particularly well-represented within mud-dominated intervals in association with *Zoophycos*, *Planolites* and *Teichichnus* (Fig. 10).

Remarks. The *Chondrites* burrows described here commonly transect other burrow systems and evidently were formed later and at a deeper level than most other forms (cf. Bromley and Ekdale, 1984, 1986). *Chondrites* is generally regarded as the

systematic feeding burrow of a polychaete or sipunculoid worm (Simpson, 1957; Osgood, 1975) although Ekdale (1977) suggested that tiny arthropods may be capable of producing such a structure. It is a widespread and cosmopolitan ichnogenus, known from deposits ranging from Cambrian to Recent in age and from abyssal (Ekdale, 1977) to shallow-marine (Gutschick and Rodriguez, 1977) in depositional setting.

Ichnogenus PHYCOSIPHON Fischer-Ooster, 1858

Phycosiphon ichnosp.

Fig. 4

Description. Winding, irregular meandering, horizontal, silt-filled burrows. Diameter 0.3–1.5 mm, generally constant within individuals. Burrows discontinuous but tight, hook-like meanders commonly preserved (Fig. 4) although more open, sinuous forms are present. Cross-cutting of burrows common on heavily bioturbated surfaces but branching is rare.

Occurrence. Occurs rarely in the Kotick Point Formation.

Remarks. This trace fossil occurs on heavily bioturbated sandy siltstone bedding planes and individual burrows are generally discontinuous. Although some short segments resemble *Cosmorhaphé* or poorly developed *Helminthoidea* traces (cf. Crimes, 1977; Chamberlain, 1978), the overall pattern of superimposed loops favours assignation to the ichnogenus *Phycosiphon*. Some traces assigned to *Phycosiphon* display spreite (e.g. Chamberlain, 1971) but spreite are not present in the type specimen depicted by Fischer-Ooster (1858) and are not considered an essential characteristic of the ichnogenus. *Phycosiphon* traces have been recorded from shallow marine and deep-sea sequences (Seilacher, 1978) but are typical of the deeper-water *Nereites* ichnofacies (Chamberlain, 1971; Kern, 1978).

Ichnogenus OPHIOMORPHA Lundgren, 1891

Ophiomorpha ichnosp.

Fig. 5

Description. Three-dimensional burrow systems, comprising horizontal, oblique and vertical cylindrical tunnels, 14–25 mm in diameter. Y-shaped dichotomous branching; tunnel widening at branching points. Characteristically show knobby, mammillated outer surface, reflecting burrow lining of elliptical-spherical pellets, 2–4 mm across. Inner burrow wall generally smooth; burrow infill is structureless and may be similar dissimilar to host sediment.

Occurrence. Recorded from sand-dominated intervals in the Kotick Point and Whisky Bay Formations. Typically occurs in medium to fine-grained, moderately to well-sorted sandstones.

Remarks. The structureless fill and pellet-lined walls indicate that these traces represent domicinal tunnels that were passively filled following evacuation by the organism. *Ophiomorpha* is commonly ascribed to burrowing decapod crustaceans (Häntzschel, 1975) and, in particular, to callianassid shrimps. The association between callianassids and *Ophiomorpha* has been demonstrated in both modern and ancient deposits (Pickett and others, 1971; Weimer and Hoyt, 1964; Curran and Frey, 1977; Frey and others, 1978). *Ophiomorpha* is often regarded as a reliable indicator of shallow-water, nearshore environments (e.g. Frey and others, 1978), but has been described from a number of deep-water, submarine fan deposits (e.g. Kern and Warme, 1974; see discussion below).

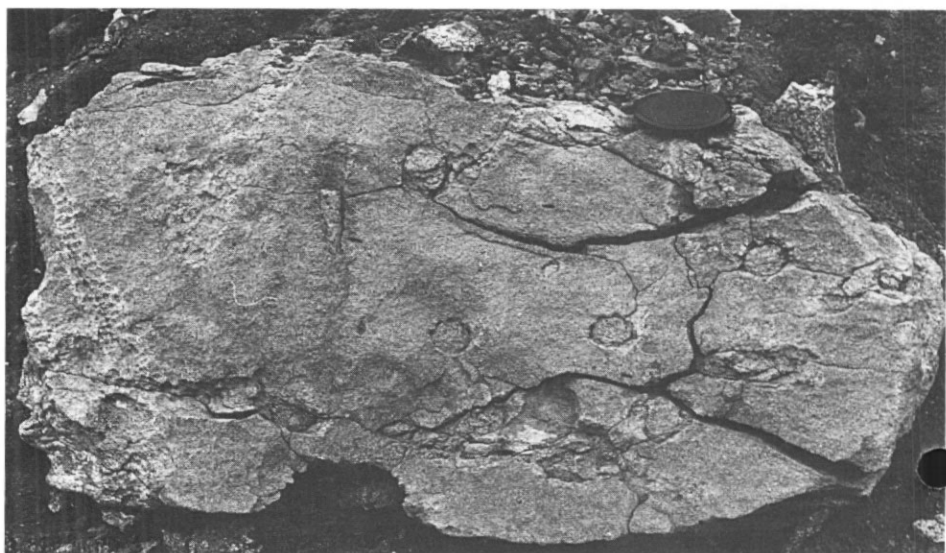


Fig. 5. *Ophiomorpha* burrows in heavily bioturbated sandstone, viewed normal to bedding. Note the distinctive imprint of pelleted burrow-lining (centre left). Gin Cove Member, Whisky Bay Formation; Lost Valley.

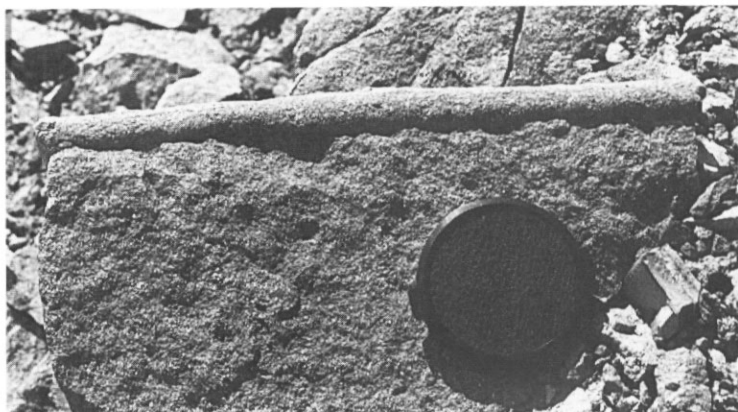


Fig. 6. Straight, cylindrical *Palaeophycus* burrow, bedding plane view. Gin Cove Member, Whisky Bay Formation; north Tumbledown Cliffs.

Ichnogenus PALAEOPHYCUS Hall, 1847

Palaeophycus ichnosp.

Fig. 6

Description. Straight or gently curved, mainly unbranched cylindrical burrows; diameter 7–15 mm, mainly parallel to bedding. Structureless sand fill, identical to host sediment. Pale-coloured silt linings up to 1 mm thick; some forms show irregular constrictions.

Occurrence. Present in sand-dominated intervals within the Whisky Bay Formation.

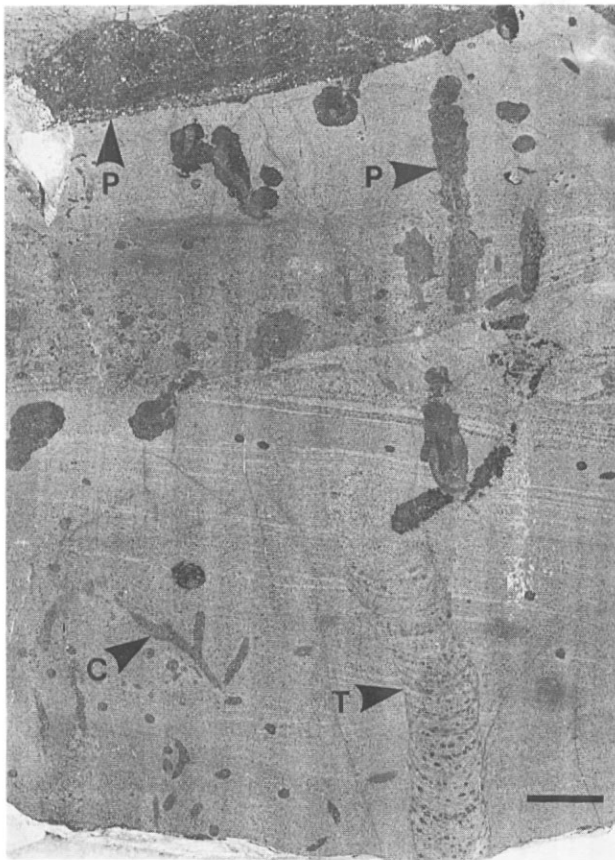


Fig. 7. Polished slab, cut normal to bedding, of calcite-cemented burrowed siltstone. Composite ichnofabric composed of *Planolites* (P) of varying size (note annulations on smaller burrows, cf. *P. annularis* Walcott), *Chondrites* (C) and *Teichichnus* (T). Note the dark speckling of fecal pellets within *Teichichnus* spreite and the upper structureless fill of this trace, representing the final position of the organism. D8311.7, scale bar = 1 cm. Kotick Point Formation; Sharp Valley.

Remarks. *Palaeophycus* is a common, facies-crossing trace fossil that is thought to represent an open dwelling burrow of a predatory or suspension-feeding organism (Pemberton and Frey, 1982).

Ichnogenus PLANOLITES Nicholson, 1873

Planolites ichnosp.

Figs. 7, 10

Description. Sub-horizontal to oblique, straight to sinuous burrows; smooth, irregular or rarely annulated wall structure. Unlined; homogeneous or mottled fill which differs from host sediment. Burrows circular or oval in cross-section, 4–16 mm in diameter, up to 130 mm long; rarely branched.

Occurrence. Common throughout the succession, particularly within mud-dominated sequences in association with *Chondrites* and *Zoophycos*.

Remarks. In a recent revision of *Planolites* and *Palaeophycus*, Pemberton and Frey

(1982) suggested that *Planolites* represents an actively back-filled ephemeral burrow, constructed by a mobile deposit feeder. Although commonly occurring in fine-grained, low-energy deposits, it is a widespread, facies-independent form that has been recorded from late Precambrian to Recent sedimentary deposits (Häntzschel, 1975).

Ichnogenus TEICHICHNUS Seilacher, 1955

Teichichnus ichnosp.

Figs. 7,10

Description. Vertical, wall-shaped, endichnial construction with retrusive, concave-upward spreite. 9–12 mm wide, up to 60 mm deep and 120 mm long. Straight to gently curved in horizontal plane; unbranched. One specimen terminates upwards in oval tube (8–10 mm across; Fig. 7) with structureless fill. Spreite commonly delineated by oval or circular, dark brown pellets (0.2–0.5 mm across).

Occurrence. *Teichichnus* was not identified in the field so its distribution is unknown. However it was found to be common in slabbed specimens of bioturbated mudstone from the Kotick Point Formation in association with *Chondrites*, *Zoophycos* and *Planolites* (Figs. 7, 10).

Remarks. *Teichichnus* is produced by the upward migration of an organism inhabiting a horizontal burrow. The uppermost, sediment-filled burrow (Fig. 7) represents the final position of the burrow prior to vacation. Ekdale (1977) suggested that the organism responsible for *Teichichnus* is a shallow burrower that moves upward to maintain its position relative to the sediment surface. *Teichichnus* is often assigned to the *Cruziana* ichnofacies, representing deposition in the shallow-marine, neritic zone (e.g. Seilacher, 1967) and is typical of low-energy, fine-grained deposits (Baldwin, 1977). It is, however, a long-ranging (Cambrian–Recent) cosmopolitan form that has been recorded from a wide spectrum of marine environments (e.g. abyssal, Ekdale, 1977; shallow subtidal, Crimes and others, 1977).

Ichnogenus THALASSINOIDES Ehrenberg, 1844

Thalassinoides ichnosp.

Fig. 8

Description. Horizontal burrow systems showing regular, dichotomous Y-shaped branching. Cylindrical tunnels 5–20 mm across: diameter typically uniform within any one network although tunnels often swell up to twice the normal diameter at the point of bifurcation. Commonly branch at about 50 mm intervals, locally producing a crudely polygonal tunnel array. Burrow walls smooth and unornamented though often showing a thin (< 1 mm) silt lining where occurring in sandstone. Some tunnels have geopetal fills of sand and calcite cement.

Occurrence. Recorded commonly from sandstone and mudstone beds in sand-dominated sequences within the Whisky Bay Formation.

Remarks. The lined nature of the burrows, the structureless sand fill and particularly the sparry calcite-cemented burrows indicate that this trace represents a dwelling burrow system that was passively filled following desertion by the occupier. *Thalassinoides* is closely comparable to modern burrows produced by thalassinidean shrimps and ancient *Thalassinoides* systems are generally attributed to crustaceans (Häntzschel, 1975; Curran and Frey, 1977). *Thalassinoides* is a common member of the *Cruziana* ichnofacies which is characteristic of the shallow subtidal shelf, between fair-weather and storm wave base (Ekdale and others, 1984). However, *Thalassinoides* has been recorded from sandy, submarine fan deposits (Kern and Warme, 1974) and

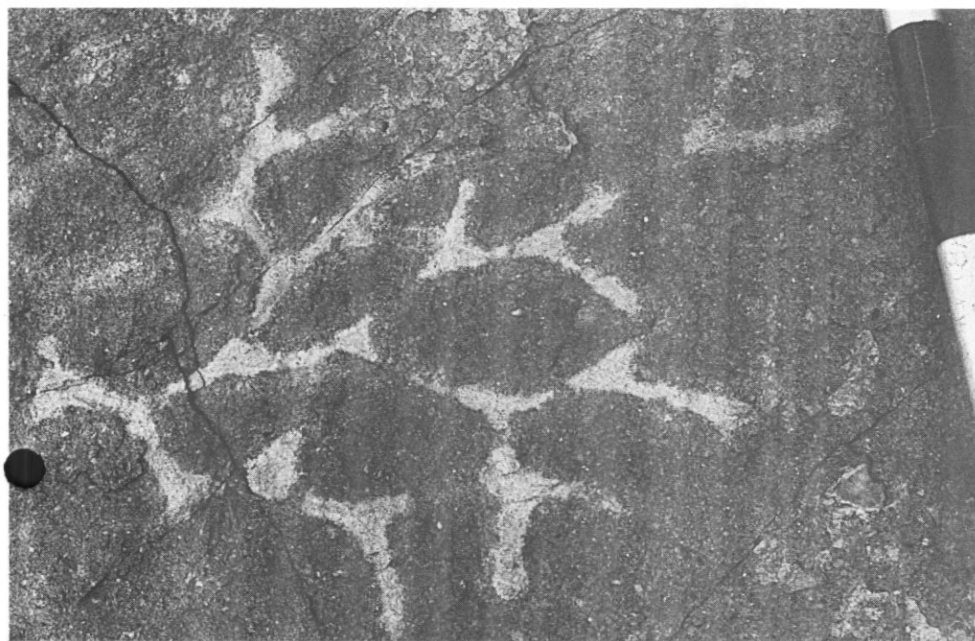


Fig. 8. Polygonal *Thalassinoides* network on sandstone bedding plane. Divisions on staff are 10 cm. Tumbledown Cliffs Member, Whisky Bay Formation; south Tumbledown Cliffs.

slope deposits (Buck and Bottjer, 1985) and its distribution is clearly not controlled by bathymetry alone.

Ichnogenus ZOOPHYCOS Massalongo, 1855

Zoophycos ichnosp.

Figs. 9, 10

Description. Mainly recognized in sections normal to bedding where it forms a series of parallel, sub-horizontal bands composed of crescentic lamellae (spreite) oriented normal to bedding or oblique, concave upwards (Fig. 10). Individual bands are 4–8 mm thick (mean 5.5 mm), up to 80 mm long on bedding-normal faces. Bands are typically gently curved with shallow concave-upwards profile; number 3–7 within any one burrow system. Band separation is typically 10 mm (range 3–18 mm); individual lamellae are 0.5–1 mm thick and are differentiated by variation in colour and grain size. Rare bedding plane exposure of *Zoophycos* shows distinctive 'roostertail' pattern of spreite spiralling from central axis (Fig. 9).

Occurrence. Common throughout the Kotick Point Formation and within fine-grained intervals of the Whisky Bay Formation. Generally found within heavily bioturbated mudstones in association with *Planolites*, *Chondrites* and *Teichichnus*.

Remarks. *Zoophycos* is a problematic trace fossil that has been variably interpreted as the product of a sea-pen (Bradley, 1973), the imprint of the gill architecture of polychaetes (Plička, 1970), a plant fossil (Plumstead, 1967) or, more commonly, as the result of systematic mining by a soft-bodied, worm-like animal (Seilacher, 1967; Wetzel and Werner, 1981). The ichnogenus is highly varied, however, and probably includes structures of different origin (see discussion in Taylor, 1967). Following



Fig. 9. Bedding plane view of bioturbated mudstone showing distinctive 'roostertail' *Zoophycos* trace (centre right). Kotick Point Formation; Kotick Point.

Ekdale (1977), the form described here is interpreted as a complex burrow system produced by systematic helical mining of the sediment by a soft-bodied, worm-like organism (see also Wetzel and Werner, 1981). Seilacher (1967) regarded *Zoophycos* as the characteristic trace fossil of a transitional assemblage representing marine environments from wave-base to bathyal depths although *Zoophycos* traces have been recorded from the complete spectrum of marine environments (Osgood and Szmuc, 1972; Häntzschel, 1975). Spreite structures from recent deep-sea muds (3800 m, SE Pacific) were compared with *Zoophycos* (Seilacher, 1967) and Ekdale (1977) described a number of forms of *Zoophycos* from Upper Cretaceous to Tertiary abyssal deposits (see also Wetzel and Werner, 1981). Indeed, the simple and curved forms of *Zoophycos* figured by Ekdale (1977) are closely comparable to those described here. Such spiral forms of *Zoophycos* are commonly associated with other complex feeding traces of the *Nereites* ichnofacies; flat forms are more typical of shallow-water environments (Häntzschel, 1975).

Rosetted trace fossil

Fig. 11

Description. Rosetted, daisy-like, epichnial trace; horizontal, flat or shallow funnel-shaped. Diameter 20–50 mm; 1–3 mm thick normal to bedding. 11–20 elongate petaloid lobes tapering to a central point. Lobes 2–4 mm across at point of maximum width, with rounded outer terminations; pseudo-branching due to local overlap of lobes. Lobes straight or rarely gently curved; composed of siltstone in sandstone host rock.

Occurrence. Recorded rarely from silty sandstones within the Kotick Point and Whisky Bay Formations.

Remarks. The ichnogenic position of this trace has not been established. Comparable unnamed structures were figured by Lessertisseur (1955, p. 52 and plate VII.7) although a central vertical burrow has not been identified in the traces described

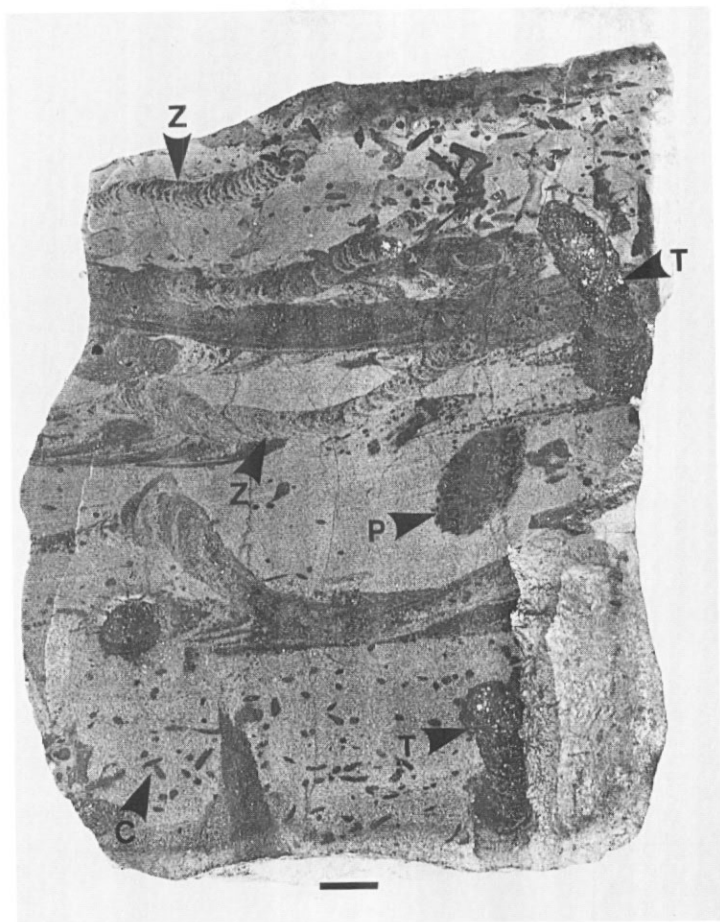


Fig. 10. Polished slab, cut normal to bedding of bioturbated sandy mudstone. Complex tiered fabric composed of *Planolites* (P), *Teichichnus* (T), *Zoophycos* (Z) and *Chondrites* (C). D8507.5, scale bar = 1 cm. Kotick Point Formation; Kotick Point.



Fig. 11. Rosetted trace fossil in bioturbated silty sandstone. D8515.13 ($\times 2$) Gin Cove Member, Whisky Bay Formation, north Tumbledown Cliffs.



Fig. 12. Steeply inclined, back-filled burrow, viewed normal to bedding. Clinometer is 6 cm across. Gin Cove Member, Whisky Bay Formation; Lost Valley.

here. They are similar to some figured specimens of *Gyrophyllites* (e.g. Książkiewicz, 1970) but this ichnogenus is not well defined and includes a variety of forms. According to Häntzschel (1975, p. W65) *Gyrophyllites* possesses club or leaf-shaped tunnels, sometimes with spreite, that radiate at different levels from a vertical or oblique shaft. The traces described here apparently occur within one sub-horizontal plane and spreite and a central burrow are not observed. Comparison with other radiate ichnogenera is also unsatisfactory; *Lorenzina* consists of short, stubby radiating grooves with a broad featureless central field, whereas the rays of *Glockerichnus* are narrow, pointed and commonly branch (see Ekdale and others, 1984). However, broadly comparable rosetted traces have been documented from a number of deep-water deposits (e.g. Książkiewicz, 1970; Pickerill, 1980).

Simple, back-filled burrows

Fig. 12

Description. Cylindrical, unbranched burrows; sub-horizontal or gently oblique, locally steep or sub-vertical. Diameter 2–20 mm. Characteristically show meniscate back-fill structure composed of alternating silty and sandy (often pelleted) laminae; some forms possess a silt wall lining.

	Mud-dominated (Slope apron, fan interchannel)	Sand-dominated (Inner fan)	
<i>Chondrites</i>	Common	Common	
<i>Planolites</i>	Common	Common	
<i>Teichichnus</i>	Rare	Absent	
<i>Zoophycos</i>	Common	Absent	
<i>Palaeophycus</i>	Absent	Common	
<i>Ophiomorpha</i>	Absent	Rare	
<i>Thalassinoides</i>	Absent	Common	
<i>Phycosiphon</i>	Rare	Rare	
Rosetted trace	Rare	Rare	
Simple backfilled	Rare	Rare	

Common
 Present
 Rare
 Absent

Fig. 13. Relative abundance of trace fossils within fine-grained and coarse-grained sedimentary sequences.

Occurrence. Present in both sand- and mud-dominated sequences throughout the succession.

Remarks. These traces represent actively back-filled burrows produced during sediment ingestion or locomotion. Many of the smaller, sub-horizontal forms resemble *Scalarituba* but there is a complete gradation between sub-horizontal and sub-vertical forms, and the characteristic meandering form and prominent scalariform ridges of *Scalarituba* are rarely seen. Horizontal back-filled burrows are often assigned to *Muensteria*; the variety in attitude of the burrows described here precludes classification in either of these ichnogenera. The large (10–20 mm diameter) sub-vertical back-filled burrows (Fig. 12) occur in close association with *Ophiomorpha* and, indeed, show similar dimensions; these traces may represent escape burrows produced by the same organism (crustacean?).

DISCUSSION

Distribution of trace fossils

The strata of the Kotick Point and Whisky Bay Formations can be broadly grouped into fine-grained, mudstone-dominated units and coarse-grained, sandstone- and conglomerate-dominated units (Fig. 2). The trace fossils described here fall into three groups relative to this facies subdivision: those occurring throughout the succession and those essentially restricted to either the fine- or the coarse-grained units (Fig. 13). Facies-independent forms include the most common traces, *Planolites* and *Chondrites*; *Phycosiphon* occurs infrequently but was recorded from siltstones within both

sedimentary associations. The rosetted traces were recognised too rarely to assess their relationship with facies.

The mud-dominated association is characterized by *Zoophycos*, typically occurring together with *Planolites*, *Chondrites* and, in places, *Teichichnus*. Forms restricted to the coarse-grained facies are *Palaeophycus*, *Thalassinoides* and *Ophiomorpha* (Fig. 13).

Environmental implications

The use of trace fossils to aid environmental interpretation of marine sequences is well-established (see Frey and Pemberton, 1984). However, the pioneering work of Seilacher (1967) in this field has undergone certain modifications as the relative importance of energy level and substrate over absolute bathymetry became apparent. Thus, trace-fossil assemblages that were thought to be characteristic of high-energy, inshore environments may be duplicated in energetic, sand-rich, deep-water environments (see Kern and Warne, 1974; Crimes, 1977; Ekdale and others, 1984). The Kotick Point and Whisky Bay Formations of James Ross Island contain representatives of both deep- and shallow-water ichnofacies. *Chondrites*, *Planolites*, *Palaeophycus* and *Teichichnus* are facies-crossing forms; *Phycosiphon* and rosetted trace fossils are commonly assigned to the deep-water *Nereites* ichnofacies, whereas horizontal *Ophiomorpha* and *Thalassinoides* are characteristic members of the shallow-marine *Cruziana* ichnofacies (Seilacher, 1967; Frey and Pemberton, 1984). However, Kern and Warne (1974) and Crimes (1977), reported *Ophiomorpha* and *Thalassinoides* burrow systems from deep-sea submarine fan deposits (see also Armentrout, 1980; Buck and Bottjer, 1985) and it is clear that the range of environmental conditions experienced in deep-sea settings can result in a wide variety of trace-fossil assemblages. In this study, the mudstone-dominated and sandstone/conglomerate-dominated intervals are typified by two distinct assemblages of trace fossils. The fine-grained units, representing deposition at the base-of-slope, marginal to submarine fans, are characterized by *Chondrites-Zoophycos-Planolites* ± *Teichichnus* (Fig. 10), an assemblage produced by infaunal deposit feeders. This assemblage is identical to that recorded from Recent fine-grained sediments in slope and deep-sea settings (Ekdale, 1977; Wetzel, 1984; Nelson, 1986) and is also commonly reported from ancient fine-grained deposits of inferred deep-water origin (e.g. Buck and Bottjer, 1985). Clearly, this assemblage characterizes low-energy, mud-dominated marine environments and Ekdale and Berger (1978) considered it typical of the deep-sea. Furthermore, the dominant presence of *Chondrites* in this assemblage, locally to the exclusion of other forms, may indicate reduced levels of oxygen in the sediment surface (Bromley and Ekdale, 1984). Where *Chondrites* forms part of a composite, tiered assemblage, it generally transects other forms and represents the last, deepest form of bioturbation (Fig. 8; see also Bromley and Ekdale, 1986).

The coarse-grained facies association is characterized by *Thalassinoides-Ophiomorpha-Palaeophycus*, an assemblage of domicinal burrows. These sandy, pebbly deposits represent the inner channelled region of coarse-grained fan systems (Ineson, 1985a); similar trace fossil assemblages have been recorded from the sand-rich, inner zone of submarine fans by Kern and Warne (1974) and Crimes (1977), and from the sandy fills of continental slope channels by Buck and Bottjer (1985).

It is clear, therefore, that most of the trace fossils recorded from this succession reflect only the local environmental conditions (substrate, energy level, oxygenation) and provide little evidence of absolute bathymetry. The deep-water setting established

by sedimentological analysis (Farquharson and others, 1984; Ineson, 1985a) is supported only by the rare occurrence of *Phycosiphon* and the rosetted trace fossil. Such traces are rarely reported from shallow-water marine sequences, and indeed, are typical members of Seilacher's *Nereites* ichnofacies representing deep-water slope or basinal environments.

ACKNOWLEDGEMENTS

I thank Mike Sharp and Steve Bell for field assistance, Chris Gilbert for photographic work and BAS colleagues for discussion and criticism of the manuscript. Dr Tom Harland is thanked for his constructive review.

Received 15 August 1986; accepted 1 October 1986

REFERENCES

- ARMENTROUT, J. M. 1980. *Ophiomorpha* from upper bathyal Eocene subsea fan facies, N.W. Washington. *American Association of Petroleum Geologists Bulletin*, Abstracts, **64**, 670.
- LDWIN, C. T. 1977. The stratigraphy and facies associations of trace fossils in some Cambrian and Ordovician rocks of north western Spain. (In CRIMES, T. P. and HARPER, J. C., eds. *Trace fossils 2. Geological Journal special issue*, 9. Liverpool, Seel House Press, 9–40.)
- BRADLEY, J. 1973. *Zoophycos* and *Umbellula* (Pennatulacea): their synthesis and identity. *Palaeogeography Palaeoclimatology Palaeoecology*, **13**, 103–28.
- BROMLEY, R. G. and EKDALE, A. A. 1984. *Chondrites*: a trace fossil indicator of anoxia in sediments. *Science*, **224**, 872–4.
- BROMLEY, R. G. and EKDALE, A. A. 1986. Composite ichnofabrics and tiering of burrows. *Geological Magazine*, **123**, 59–65.
- BUCK, S. P. and BOTTJER, D. J. 1985. Continental slope deposits from a Late Cretaceous, tectonically active margin, southern California. *Journal of Sedimentary Petrology*, **55**, 843–55.
- CHAMBERLAIN, C. K. 1971. Morphology and ethology of trace fossils from the Ouachita Mountains, southeastern Oklahoma. *Journal of Paleontology*, **45**, 212–46.
- CHAMBERLAIN, C. K. 1978. Recognition of trace fossils in cores. (In BASAN, P. B. ed. *Trace fossil concepts*. Society of Economic Paleontologists and Mineralogists, Short course, **5**, 119–66.)
- CRIMES, T. P. 1977. Trace fossils of an Eocene deep-sea sand fan, northern Spain. (In CRIMES, T. P. and HARPER, J. C. eds. *Trace fossils 2. Geological Journal special issue*, 9. Liverpool, Seel House Press, 71–90.)
- CRIMES, T. P., LEGG, I., MARCOS, A. and ARBOLEYA, M. 1977. ?Late Precambrian-low Lower Cambrian trace fossils from Spain. (In CRIMES T. P. and HARPER, J. C., eds. *Trace fossils 2. Geological Journal special issue*, 9. Liverpool, Seel House Press, 91–138.)
- CURRAN, H. A. 1985. The trace fossil assemblage of a Cretaceous nearshore environment: Englishtown Formation of Delaware, U.S.A. (In CURRAN, H. A. ed. *Biogenic structures: their use in interpreting depositional environments*. Society of Economic Paleontologists and Mineralogists, Special Publication, **35**, 261–76.)
- CURRAN, A. and FREY, R. W. 1977. Pleistocene trace fossils from North Carolina (U.S.A.) and their Holocene analogues. (In CRIMES, T. P. and HARPER, J. C. eds. *Trace fossils 2. Geological Journal special issue*, 9. Liverpool, Seel House Press, 139–62.)
- EKDALE, A. A. 1977. Abyssal trace fossils in worldwide Deep Sea Drilling Project cores. (In CRIMES, T. P. and HARPER, J. C. eds. *Trace Fossils 2. Geological Journal special issue*, 9. Liverpool, Seel House Press, 163–82.)
- EKDALE, A. A. and BERGER, G. 1978. Deep sea ichnofacies: modern organic traces on and in pelagic carbonates of the western equatorial Pacific. *Palaeogeography Palaeoclimatology Palaeoecology*, **23**, 263–78.
- EKDALE, A. A., BROMLEY, R. G. and PEMBERTON, S. G. 1984. Ichnology. The use of trace fossils in sedimentology and stratigraphy. *Society of Economic Paleontologists and Mineralogists, Short course*, **15**, 317 pp.
- FARQUHARSON, G. W., HAMER, R. D. and INESON, J. R. 1984. Proximal volcanoclastic sedimentation in a Cretaceous back-arc basin, northern Antarctic Peninsula (In KOKELAAR, B. P. and HOWELLS, M. F. eds. *Marginal Basin Geology*. Geological Society of London, Special Publication, **16**, 219–29.)
- FISCHER-OOSTER, C. VON 1858. Die fossilen Fucoiden der Schweizer Alpen, nebst Erörterungen über deren geologisches Alter. pp. 72. Huber, Bern.

- FREY, R. W., HOWARD, J. D. and PRYOR, W. A. 1978. *Ophiomorpha*: its morphologic, taxonomic and environmental significance. *Palaeogeography Palaeoclimatology Palaeoecology*, **23**, 199–229.
- FREY, R. W. and PEMBERTON, S. G. 1984. Trace fossil facies models. (In WALKER, R. G. ed. *Facies models*. Geoscience Canada, Reprint Series, **1**, 189–207.)
- GUTSCHICK, R. C. and RODRIGUEZ, J. 1977. Late Devonian–Early Mississippian trace fossils and environments along the Cordilleran Miogeocline, western United States. (In CRIMES, T. P. and HARPER, J. C. eds. *Trace fossils 2. Geological Journal special issue*, **9**. Liverpool, Seel House Press, 195–208.)
- HÄNTZSCHEL, W. 1975. Trace fossils and problematica. (In TEICHERT, C., ed. *Treatise on invertebrate palaeontology*. New York, Geological Society of America, and Lawrence, Kansas, University of Kansas Press. Part W, Supplement 1.)
- INESON, J. R. 1985a. A slope apron–submarine fan complex in the Lower Cretaceous of Antarctica. *International Association of Sedimentologists, 6th European Regional Meeting, Lleida, Spain 1985*, Abstracts, 203–6.
- INESON, J. R. 1985b. Submarine glide blocks from the Lower Cretaceous of the Antarctic Peninsula. *Sedimentology*, **32**, 659–70.
- INESON, J. R., CRAME, J. A. and THOMSON, M. R. A. 1986. Lithostratigraphy of the Cretaceous strata of west James Ross Island, Antarctica. *Cretaceous Research*, **7**, 141–59.
- KERN, J. P. 1978. Trails from the Vienna Woods: Palaeoenvironments and trace fossils of Cretaceous to Eocene flysch, Vienna, Austria. *Palaeogeography Palaeoclimatology Palaeoecology*, **23**, 230–62.
- KERN, J. P. and WARME, J. E. 1974. Trace fossils and bathymetry of the Upper Cretaceous Point Loma Formation, San Diego, California. *Geological Society of America Bulletin*, **85**, 893–900.
- KSIĄŻEWICZ, M. 1970. Observations on the ichnofauna of the Polish Carpathians. (In CRIMES, T. P. and HARPER, J. C. eds. *Trace fossils. Geological Journal special issue*, **3**. Liverpool, Seel House Press, 283–322.)
- LESSERTISSEUR, J. 1955. Traces fossiles d'activité animale et leur signification paléobiologique. *Memoires de la Société Géologique de France*, **74**, pp. 150.
- NELSON, C. S. 1986. Bioturbation in middle bathyal, Cenozoic nannofossil oozes and chalks, southwest Pacific. *Initial Reports of the Deep Sea Drilling Project*, vol. XC, part 2, 1189–99.
- OSGOOD, R. G. 1975. The history of invertebrate ichnology. (In FREY, R. W. ed. *The study of trace fossils*. Springer-Verlag, New York, 3–12.)
- OSGOOD, R. G. and SZMUC, E. G. 1972. The trace fossil *Zoophycos* as an indicator of water depth. *Bulletin of American Paleontology*, **62**, 1–22.
- PEMBERTON, S. G. and FREY, R. W. 1982. Trace fossil nomenclature and the *Planolites*–*Palaeophycus* dilemma. *Journal of Paleontology*, **56**, 843–81.
- PICKERILL, R. K. 1980. Phanerozoic flysch trace fossil diversity – observations based on an Ordovician flysch ichnofauna from the Aroostook–Matopedia Carbonate Belt of northern New Brunswick. *Canadian Journal of Earth Sciences*, **17**, 1259–70.
- PICKETT, T. E., KRAFT, J. C. and SMITH, K. 1971. Cretaceous burrows – Chesapeake and Delaware Canal, Delaware. *Journal of Paleontology*, **45**, 209–11.
- PLIČKA, M. 1970. *Zoophycos* and similar fossils. (In CRIMES, T. P. and HARPER, J. C. eds. *Trace fossils. Geological Journal special issue*, **3**. Liverpool, Seel House Press, 361–70.)
- PLUMSTEAD, E. P. 1967. A general view of the Devonian fossil plants found in the Cape System of South Africa. *Paleontologia Africana*, **10**, 1–12.
- SEILACHER, A. 1967. Bathymetry of trace fossils. *Marine Geology*, **5**, 413–28.
- SEILACHER, A. 1978. Use of trace fossils for recognizing depositional environments. (In BASAN, P. B. ed. *Trace fossil concepts*. Society of Economic Paleontologists and Mineralogists, Short course, **5**, 175–201.)
- SIMPSON, S. 1957. On the trace fossil *Chondrites*. *Quarterly Journal of the Geological Society of London*, **112**, 475–96.
- TAYLOR, B. J. 1967. Trace fossils from the Fossil Bluff Series of Alexander Island. *British Antarctic Survey Bulletin*, No. 13, 1–30.
- WEIMER, R. J. and HOYT, J. H. 1964. Burrows of *Callianassa major* Say, geologic indicators of littoral and shallow neritic environments. *Journal of Paleontology*, **38**, 761–7.
- WETZEL, A. 1984. Bioturbation in deep-sea fine-grained sediments: influence of sediment texture, turbidite frequency and rates of environmental change. (In STOW, D. A. V. and PIPER, D. J. W. eds. *Fine-grained sediments*. Geological Society of London. Special Publication, **15**, 595–608.)
- WETZEL, A. and WERNER, F. 1981. Morphology and ecological significance of *Zoophycos* in deep-sea sediments off NW Africa. *Palaeogeography Palaeoclimatology Palaeoecology*, **32**, 185–212.